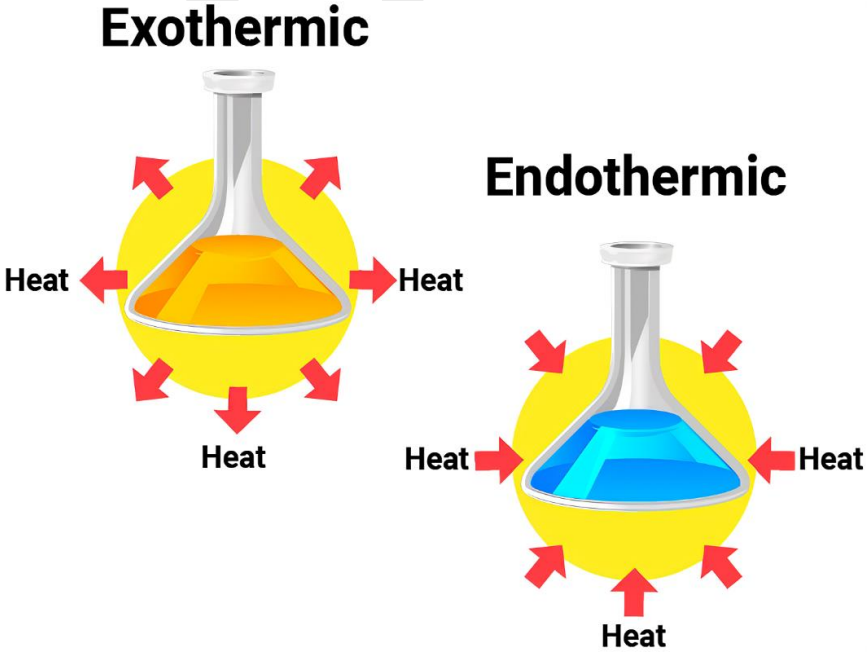
Cambridge OL

Chemistry

CODE: (5070)

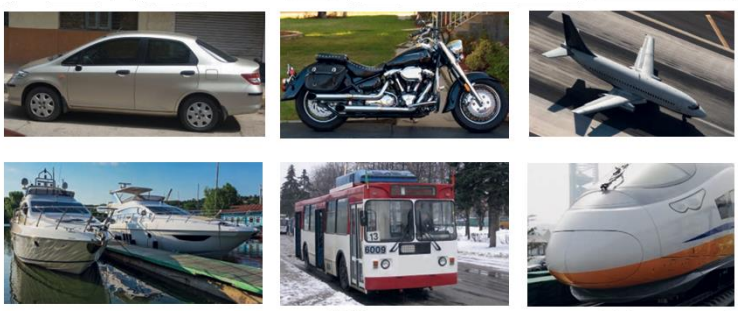
Chapter 06

Chemical energetics



6.1 Substances from petroleum

What do the modes of transport in Figure 6.1 have in common?



▲ **Figure 6.1** What type of fuel do these modes of transport use?

They all use liquids obtained from **petroleum** as fuels.

Oil refining

Hydrocarbons, a complex mixture of compounds, are the basis of **organic compounds**. These organic compounds, based on carbon atom chains, are essential for all living things. Petroleum is a major fuel source and a vital raw material for everyday products like polymers and medicines.

Key definition
Hydrocarbons are compounds that contain hydrogen and carbon only.

Petroleum is not very useful to us until it has been processed. The process, known as oil refining, is carried out at an **oil refinery**. Refining involves separating petroleum into various batches or **fractions**. Chemists use a technique called **fractional distillation** to separate the different fractions.

The process of fractionation involves collecting hydrocarbon molecules with boiling points in a specific range, such as petrol. These molecules, which have shorter and longer chains, condense at different levels. The liquids are collected on trays and separated into different fractions. The properties of these fractions, such as **viscosity** and **volatility**, determine their uses. For instance, viscous fractions, like petrol, are used as lubricants, while volatile fractions, like gasoline, are ideal for engines.

In general, the properties of the fractions obtained from this fractional distillation change from the bottom to the top of the tower with:
» Lowering boiling points
» Higher volatility
» Lower viscosity
» Decreasing chain length.

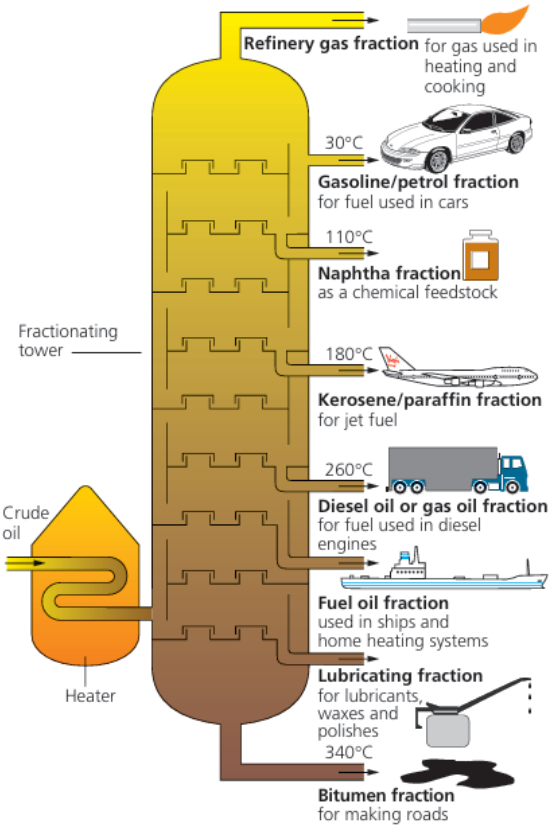
Key definition
Petroleum is a mixture of hydrocarbons.

▲ **Figure 6.3** Oil drilling rig off Labuan island, northwest coast of Borneo

▲ **Figure 6.2** Petroleum is a mixture of hydrocarbons

▲ **Figure 6.3** Oil drilling rig off Labuan island, northwest coast of Borneo

a Fractional distillation of petroleum in a refinery



b Uses of the different fractions obtained from petroleum

▲ **Figure 6.4**

6.2 Fossil fuels

Coal, petroleum and natural gas are all examples of fossil fuels. The term '**fossil fuels'** is derived from the fact that they are formed from dead plants and animals which were fossilised over 200 million years ago (Figure 6.5)

6.3 What is a fuel?

A fuel is any substance which can be conveniently used as a source of energy. Fossil fuels release energy in the form of heat when they undergo **combustion**.

The perfect fuel would:

» Be cheap
» Be available in large quantities
» Be safe to store and transport
» Be easy to ignite and burn, causing no pollution
» Release no greenhouse gases
» Be capable of releasing large amounts of energy.

$$\text{fossil fuel} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

For example, natural gas burns readily in air (Chapter 12, p. 185).

$$\text{methane} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

6.4 Alternative sources to fossil fuels

Non-renewable fuels, such as fossil fuels, are not being replaced at the same rate as they are being used up, necessitating careful consideration of alternative, **renewable** energy sources.

These include:

» Nuclear » tidal » wave » geothermal » solar.
» Hydroelectric » Biomass and biogas » Hydrogen » Wind

6.5 Exothermic and endothermic reactions

Combustion

When natural gas burns in a plentiful supply of air it produces a large amount of energy.

$$\text{methane} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

Key definition
An **exothermic** reaction transfers thermal energy to its surroundings, leading to an increase in the temperature of the surroundings.

Complete combustion, an **exothermic reaction**, involves the transfer of thermal energy to the surroundings, resulting in the production of toxic gas carbon monoxide in limited air supply.

The **incomplete combustion** of methane is depicted through a **reaction pathway diagram**, illustrating the energy changes and exothermic nature of chemical reactions.

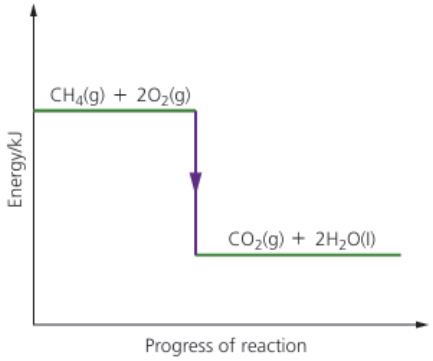
An **endothermic reaction** is a process where thermal energy is taken in from the surroundings, causing a decrease in temperature. An example is using a cold pack to treat an injury, where the water reacts with the chemical, resulting in a decrease in temperature.

Key definition
An **endothermic** reaction transfers thermal energy from the surroundings leading to a decrease in the temperature of the surroundings.

Bond energy is the energy required for breaking chemical bonds in reactants during a reaction, while it is released when new bonds are formed in products, indicating exothermic processes.

$$\text{methane} + \text{oxygen} \rightarrow \text{carbon monoxide} + \text{water}$$

$$2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(l)$$

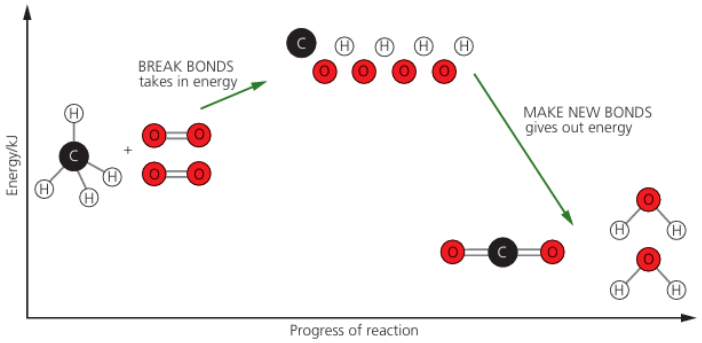


▲ **Figure 6.7** A reaction pathway diagram for the complete combustion of methane

Using the data in Table 6.1, which tells us how much energy is needed to break a chemical bond and how much is given out when it forms, we can calculate how much energy is involved in each stage.

▼ **Table 6.1** Bond energy data

Bond	Bond energy kJ/mol
C–H	435
O=O	497
C=O	803
H–O	464
C–C	347
C–O	358



▲ **Figure 6.8** Breaking and forming bonds during the combustion of methane

Bond breaking

The initial step involves determining the energy required to break the bonds between methane and oxygen gas, where one mole of methane reacts with two moles of oxygen gas.

Breaking 4 C–H bonds in 1 mole of methane requires:
4 × 435 = 1740 kJ

Breaking 2 O=O bonds in the 2 moles of oxygen requires:
2 × 497 = 994 kJ
Total = 2734 kJ of energy

Making bonds

Making two C=O bonds in 1 mole of carbon dioxide gives out:
2 × 803 = 1606 kJ
Making four H–O bonds in the 2 moles of water gives out: 4 × 464 = 1856 kJ
Total = 3462 kJ of energy

This is the total amount of energy given out when the bonds in the products are formed.

$$\begin{aligned}\text{energy difference} &= \text{energy required to break bonds} \\ &\quad - \text{energy given out when bonds are made} \\ &= 2734 - 3462 \\ &= -728 \text{ kJ/mol of methane burned}\end{aligned}$$

Key definition
The transfer of thermal energy during a reaction is called the **enthalpy change, Δ*H*, of the reaction**.

In an exothermic reaction, chemicals lose energy to the surroundings, while in an endothermic reaction, they gain energy from the surroundings. The **enthalpy changes of reaction**, represented by ΔH, represents the energy exchange between reactants and products.

When fuels, such as methane, are burned they require energy to start the chemical reaction. This minimum amount of energy is known as the **activation energy**, E_a (Figure 6.9). It is the minimum amount of energy which is needed to allow the colliding particles in the reaction mixture to form products.

Key definition
The **activation energy**, E_a, is the minimum energy that colliding particles must have in order to react.

The activation energy, a crucial component of the reaction pathway, plays a significant role in the initial bond breaking process of methane-oxygen bonding.

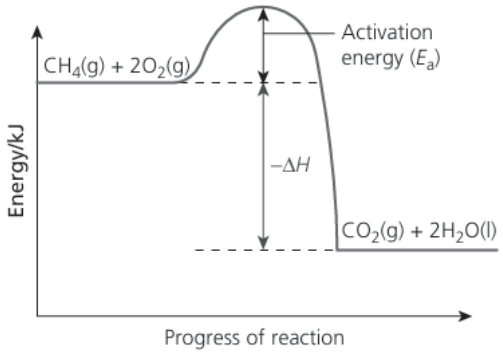
Endothermic reactions, less common than exothermic ones, involve energy absorption, resulting in products with greater energy than reactants, particularly in high-temperature reactions like nitrogen-oxygen gas reactions.

$$\text{nitrogen} + \text{oxygen} \rightarrow \text{nitrogen(II) oxide}$$

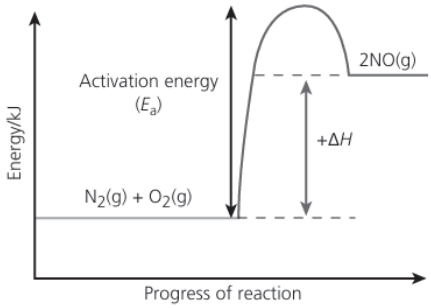
$$N_2(g) + O_2(g) \rightarrow 2NO(g)\ \Delta H = +181\ \text{kJ/mol}$$

Dissolving, photosynthesis, and thermal decomposition are endothermic processes, with ΔH values expressed in kJ/mol in equations.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l);\ \Delta H = -728\ \text{kJ/mol}$$



▲ **Figure 6.9** A reaction pathway diagram for methane with oxygen



▲ **Figure 6.10** A reaction pathway diagram for nitrogen with oxygen

Revision questions

1) a) The following are two examples of substitution reactions. Only the reaction involving chlorine is a photochemical reaction.

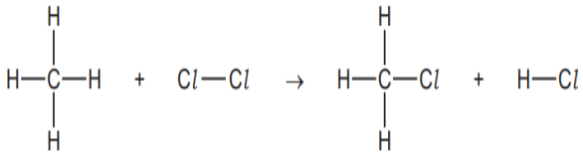
$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

$$CH_4 + Br_2 \rightarrow CH_3Br + HBr$$

i)Explain the phrase substitution reaction.
ii)How do photochemical reactions differ from other reactions?

b) Bond forming is exothermic; bond breaking is endothermic.
Explain the difference between an exothermic reaction and an endothermic reaction.

c) Use the bond energies to show that the following reaction is exothermic.
Bond energy is the amount of energy (kJ/mol) which must be supplied to break one mole of the bond.



Bond energies in kJ/mol
Cl-Cl +242
C-Cl +338
C-H +412
H-Cl +431

2)a) Period 3 contains the elements sodium to argon. This question asks about the chemistry of each of the Period 3 elements or their compounds.
Sodium nitrate is a white crystalline solid. When heated it melts and the following reaction occurs.

$2NaNO_3$ (I) → $2NaNO_2$ (I) + O_2(g)

A 3.40 g sample of sodium nitrate is heated.
Calculate the
• number of moles of $NaNO_3$ used,
• number of moles of O_2 formed,
• volume of O_2 formed, in dm^3 (measured at r.t.p.).

b) Magnesium reacts slowly with warm water to form a base, magnesium hydroxide.
i) Explain what is meant by the term base.
ii) Write a chemical equation for the reaction between magnesium and warm water.

c) Aluminium oxide is amphoteric. It is insoluble in water.
Describe experiments to show that aluminium oxide is amphoteric.

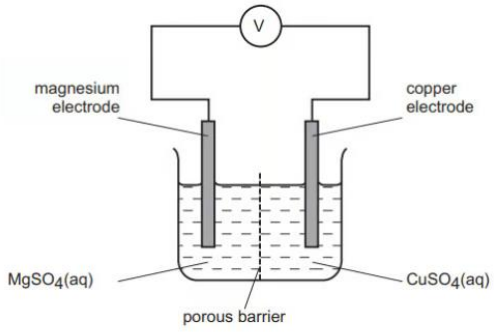
d)Silicon (IV) oxide has a giant structure.
i)Name the type of bonding in silicon (IV) oxide.
ii)Give two physical properties of silicon (IV) oxide.

3) a) Chemical reactions are always accompanied by an energy change.
Aluminium is extracted by the electrolysis of a molten mixture which contains aluminium oxide, Al2O3. This decomposes to form aluminium at the negative electrode and oxygen at the positive electrode.

i)Write an ionic equation for the reaction at the negative electrode.
ii)Complete the ionic equation for the reaction at the positive electrode.

$2O^{2-} \rightarrow \ldots\ldots + \ldots\ldots$

iii)Is the reaction exothermic or endothermic? Explain your answer.



b) The cell shown below can be used to determine the order of reactivity of metals.
i)Is the reaction in the cell exothermic or endothermic? Explain your answer.

ii)Explain why the mass of the magnesium electrode decreases and the mass of the copper electrode increases.

iii)How could you use this cell to determine which is the more reactive metal, magnesium or manganese?

c) The combustion of propane, C_3H_8, is exothermic.
Give an equation for the complete combustion of propane.

d) Photosynthesis is an unusual endothermic reaction.
i)Where does the energy for photosynthesis come from?

3) a) The balanced equation for the combustion of ethene is

$$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)$$

Bond	Bond energy (kJ / mol)
C=C	614
C-H	414
O-H	463
C=O	804
O=O	498

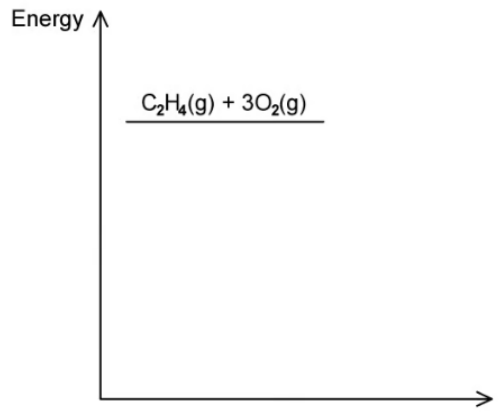
Use the information in the table to calculate the following:
i)Energy required to break the bonds
ii)Energy released when bonds are made
iii)Energy change for the reaction

b) Complete the reaction pathway diagram for the reaction in part (a). Include an arrow which clearly shows the energy change during the reaction.

c) The forward reaction to produce ethanol from ethene is shown below.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g) \quad \Delta H = -45\ kJ/mol$$

In terms of temperature and pressure, explain which conditions would give an economically viable yield.

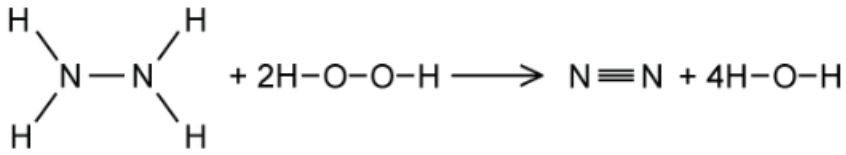


4) a) The table below has some enthalpy data for a different chemical reaction. Hydrazine, N_2H_4 can react with hydrogen peroxide in an exothermic reaction, as shown below.

$N_2H_4 + 2H_2O_2 \rightarrow N_2 + 4H_2O \quad \Delta H = -789\ kJ / mol$

Bond	Bond Energy kJ / mol
N-N	+158
N ≡ N	+945
O-H	+463
O-O	+144

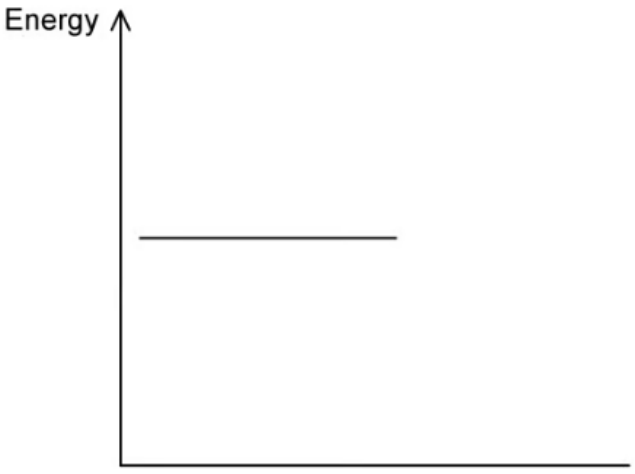
The structures of the reactants and products are shown.



Using the reaction equation and the data in the table above, calculate the value of the N-H bond in hydrazine.

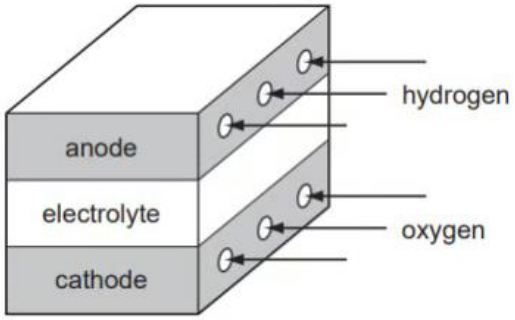
b) Draw a dot cross diagram for hydrazine.
Use x to represent electrons from nitrogen atoms
Use o to represent electrons from hydrogen atoms

c) When nitrogen and oxygen are heated to very high temperatures, they combine to form nitrogen monoxide and a lot of heat is absorbed in this reaction.
Complete the reaction pathway diagram to show the formation of nitrogen monoxide from nitrogen and oxygen.



5) Fuel cells are used in spacecraft to produce electrical energy.
Hydrogen and oxygen react to form water.

$$2H_2 + O_2 \rightarrow 2H_2O$$



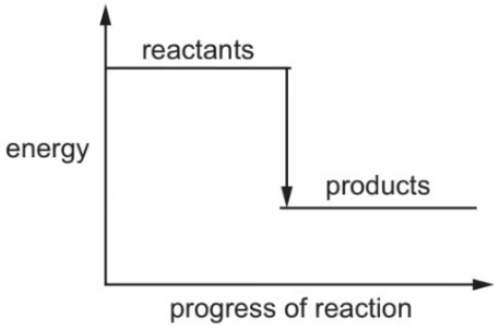
i)Give an example of bond breaking in the above reaction.
ii)Give an example of bond forming in the above reaction.
iii) Is the change given in (i) exothermic or endothermic?

i)Give two reasons why hydrogen may be the ideal fuel for the future.

ii)Suggest a reason why hydrogen is not widely used now.

6)a) Bromine reacts with hydrogen sulfide, H_2S.
Complete the chemical equation for this reaction.

$$\ldots\ldots + H_2S \rightarrow \ldots\ldots HBr + S$$



b) The energy level diagram for this reaction is shown.

Explain how this diagram shows that the reaction is exothermic.

7) a) The reaction of iron (II) carbonate with hydrochloric acid is exothermic. What is meant by the term exothermic?

b) Rust contains compounds of iron.
State two conditions needed for iron to rust.

8) a) The first three elements in Period 6 of the Periodic Table of the Elements are caesium, barium and lanthanum.

How many more protons, electrons and neutrons are there in one atom of lanthanum than in one atom of caesium.
Use your copy of the Periodic Table of the Elements to help you.

number of protons……
number of electrons……
number of neutrons……

b) All three metals can be obtained by the electrolysis of a molten halide. The electrolysis of the aqueous halides does not produce the metal.

i) Complete the equation for the reduction of lanthanum ions at the negative electrode (cathode).

$$La^{3+} + \ldots\ldots\ldots\ldots \rightarrow \ldots\ldots\ldots\ldots$$

ii) Name the three products formed by the electrolysis of aqueous caesium bromide.

c) Barium chloride is an ionic compound. Draw a diagram that shows the formula of the compound, the charges on the ions and gives the arrangement of the valency electrons around the negative ion.
The electron distribution of a barium atom is 2.8.18.18.8.2
Use x to represent an electron from a barium atom. Use o to represent an electron from a chlorine atom.

d) All three metals react with cold water. Complete the word equation for these reactions.
metal + water → …… + ……

9) a) The reaction of iron (II) carbonate with hydrochloric acid is exothermic.
What is meant by the term exothermic?

b) The reaction between ethanoic acid and ethanol is exothermic. Draw an energy level diagram for this reaction.
On your diagram label:

- The reactants and products
- The energy change of the reaction, AH.